

ARMY RESEARCH LABORATORY



Validation of the Atmospheric Transmission Large-Area Analysis System (ATLAS)

by Max P. Bleiweiss



ARL-TR-544

February 1995

19950501 105

DTIC QUALITY INSPECTED 3

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The citation of trade names and names of manufacturers in this report is not to be construed as official Government indorsement or approval of commercial products or services referenced herein.

Destruction Notice

When this document is no longer needed, destroy it by any method that will prevent disclosure of its contents or reconstruction of the document.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE February 1995	3. REPORT TYPE AND DATES COVERED Final
4. TITLE AND SUBTITLE Validation of the Atmospheric Transmission Large-Area Analysis System (ATLAS)			5. FUNDING NUMBERS
6. AUTHOR(S) Max P. Bleiweiss			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Battlefield Environment Directorate Attn: AMSRL-BE-A White Sands Missile Range, NM 88002-5501			8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-544
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory 2800 Powder Mill Road Adelphi, MD 20783-1145			10. SPONSORING / MONITORING AGENCY REPORT NUMBER ARL-TR-544
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 words) The Atmospheric Transmission Large-Area Analysis System (ATLAS) is a unique tool that has been under development at the U.S. Army Research Laboratory since the mid-1980's. ATLAS is a nonintrusive, passive technique capable of producing two-dimensional transmittance maps of a smoke cloud in a plane perpendicular to the main-optical-axis line of sight (LOS). (Off-axis LOSs are not perpendicular but are in a fan with an angular intersect determined by the overall field of view of the imager.) (The accuracy and precision of the transmission values depends on the test conditions during which the measurements are made but can be defined through the error analyses discussed in this report. The spatial resolution of the resulting transmission maps is also test specific, but, typically, is of the order of a few tens of centimeters. The temporal resolution is determined by the video rates of the imaging system, which, after preliminary low-pass filtering, yields maps at 10 Hz.) ATLAS is at the stage of development that it is used on a regular basis to support smoke/obscurant field tests. For this reason, a validation process was defined and implemented in 1989. This report documents the completion of that effort as a major milestone for the laboratory during FY92. In addition, the capabilities and limitations of the ATLAS technique are discussed in detail.			
14. SUBJECT TERMS ATLAS, transmission, smoke, obscurant			15. NUMBER OF PAGES 47
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR

Acknowledgments

The existence of the Atmospheric Transmission Large-Area Analysis System (ATLAS) technique is possible because of the dedicated and inspired effort of several individuals at U.S. Army Research Laboratory (ARL) at White Sands Missile Range, NM, Physical Science Laboratory of New Mexico State University, Colorado State University, and Metsat, Inc. The individuals include Mr. G. Blackman who first developed the concept (now retired); Dr. D. Hooch for valuable guidance and insight; Mssrs. R. Howerton, K. Payne, and T. King for all of the laborious processing of data and refining of the algorithms; Mssrs. R. Tellez, D. Stogden, S. McCracken, and O. DeAnda for data acquisition; and Dr. T. Vonder Haar and his colleagues, including Mr. A. Jones and Dr. G. Stephens, for their review and analyses of the ATLAS technique. The financial and moral support of Mr. Tony Van de Wal's group (first at Program Manager/Smoke and Obscurants, next at Chemical Research Development Engineering Center, and now at ARL), including Mssrs. Walter Klimek and Robert Laughman, is greatly appreciated. Without the support and encouragement of ARL this effort could not have been realized. There are several others who have had a part in this effort, but neither space nor my memory and knowledge allow a complete list, so, with apologies, I will end here.

Accession For	
NTIS	CRA&I <input checked="checked" type="checkbox"/>
DTIC	TAB <input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification _____	
By _____	
Distribution / _____	
Availability Codes	
Dist	Avail and/or Special
A-1	

Contents

Acknowledgments	1
1. Introduction	5
2. Validation Process	9
2.1 <i>Physics</i>	9
2.2 <i>Assumptions</i>	10
2.3 <i>Limitations</i>	11
2.4 <i>Error Analyses</i>	12
2.5 <i>Mitigation Efforts</i>	17
3. Conclusions	25
References	27
Acronyms and Abbreviations	29
Distribution	31

Figures

1. The ATLAS process shown schematically. The scene, containing a variety of natural and manmade objects, is imaged before and during the presence of smoke. The images, acquired with a thermal imager, are recorded to video tape for later data reduction that is accomplished with a pc-based image processing system 7
2. A pretrial image from a typical smoke trial. This scene provides the GLB used in the ATLAS algorithm. Each pixel location provides its unique grey level 17
3. An image of the scene of figure 2 with smoke present. The grey level array provides the GLCs for equation (4) 18
4. The transmittance map (transmittance in percent is proportional to grey level -- 0 percent is black and 100 percent is light grey) that results from the ATLAS processing of the images in figures 2 and 3. The cloud grey level, GLS, is a global constant and the same value applies everywhere in the image; therefore, there is no GLS image to correspond to those for GLC and GLB 19
5. The error map that results from the application of the error analyses to this example shown in figures 2, 3, and 4. (Black is 0 percent error and white is equal to or greater than 243 percent error.) In theory, such a map should be provided with each transmittance image; in practice, only regions of large uncertainty are identified at the current time even though the capability exists to do the full analyses 20
6. Rapid and large fluctuations in background radiance 22

1. Introduction

The Atmospheric Transmission Large-Area Analysis System (ATLAS) is a nonintrusive, passive technique in which two-dimensional transmittance maps of a smoke cloud in a plane perpendicular to the line of sight (LOS) are produced. (Off-axis LOSs are not perpendicular but are in a fan with the apex at the imager; however, because of the geometry, the approximation is not too far wrong.) Generally, ATLAS is a technique that uses an imager as a receiver and the natural background scene radiance or targets of opportunity* as the source to form a transmissometer system. Figure 1 is a schematic of the process. Typically, the background scene radiance, prior to the presence of smoke, is recorded and saved for comparison to the scene when smoke is present. Through a variety of algorithms, the cloud radiance under optically thick conditions is determined and, along with the processing of the two scenes (clear air and with aerosol present), yields a transmittance map. The advantage in using ATLAS over conventional techniques is its passive, nonintrusive capability and ability to measure the whole scene as opposed to a single LOS. A traditional transmissometer only samples the equivalence of a single pixel in a scene, whereas, ATLAS samples $\approx 200 \times 200$ pixels (the image array size). For typical test scenarios, this yields spatial resolution for the transmittance field of the order of a few tens of centimeters; if desired, it could be as small as a few centimeters. The temporal resolution is determined by the video rates of the imaging systems being used (30 frames/s; low-pass filtered to yield data at 10 Hz). A disadvantage of the current instrumentation setup is that the precision of the transmittance measurements determined by ATLAS is a few percent, because of low dynamic range. More conventional systems can measure transmittance levels of fractions of a percent. When there is insufficient natural scene radiance or targets of opportunity for determining transmittance, it is possible to place sources in the field of view and use the imager as the receiver and retain a certain degree of versatility. This latter mode can also be used for measurements in other portions of the spectrum

*A "target of opportunity," as used in this report, is defined as a localized region of the image that is considerably hotter than the surrounding background. The target of opportunity may be caused by a natural or cultural feature that appears hotter.

(visible, near-infrared (IR)) where scattering may dominate and the ATLAS algorithm is no longer valid.

ATLAS provides two-dimensional transmittance through the cloud so the full vertical and horizontal extent of the cloud, relative to its screening characteristics, can be determined. ATLAS can also assess impossible LOSs (elevated platform (slant path) or other horizontal LOSs not amenable to instrumentation) that would otherwise be inaccessible to measurement. Another ATLAS utility characterizes diffusion and transport processes to a degree not previously attained.* [1] In addition, the creation of a library of real smoke clouds for use in simulations/simulators is just being realized. [2] It is only with ATLAS that such measurements and tools are available.†

Because of the importance of the products of ATLAS processing, and as with any measurement technique, it is necessary to document the capabilities and limitations of the process. This effort is described in this report as a validation effort. This report describes the validation process used on ATLAS and the progress and results of the validation. It is to be understood that the validation process is an evolving and continual process as is the ATLAS technique itself. The progress with the ATLAS technique will develop as it is used and as new situations requiring its use become known.

*Cloud 8904 was been supplied in part to, and is being used by, the developers of the Battlefield Environment Weather Simulation System. [3]

†This statement is valid because there are no other systems capable of freezing the cloud; for example, LIDAR systems require pulse rates of the order of tens of kHz to sample the cloud rapidly enough to ensure no significant cloud movement during the measurement period; such systems do not exist.

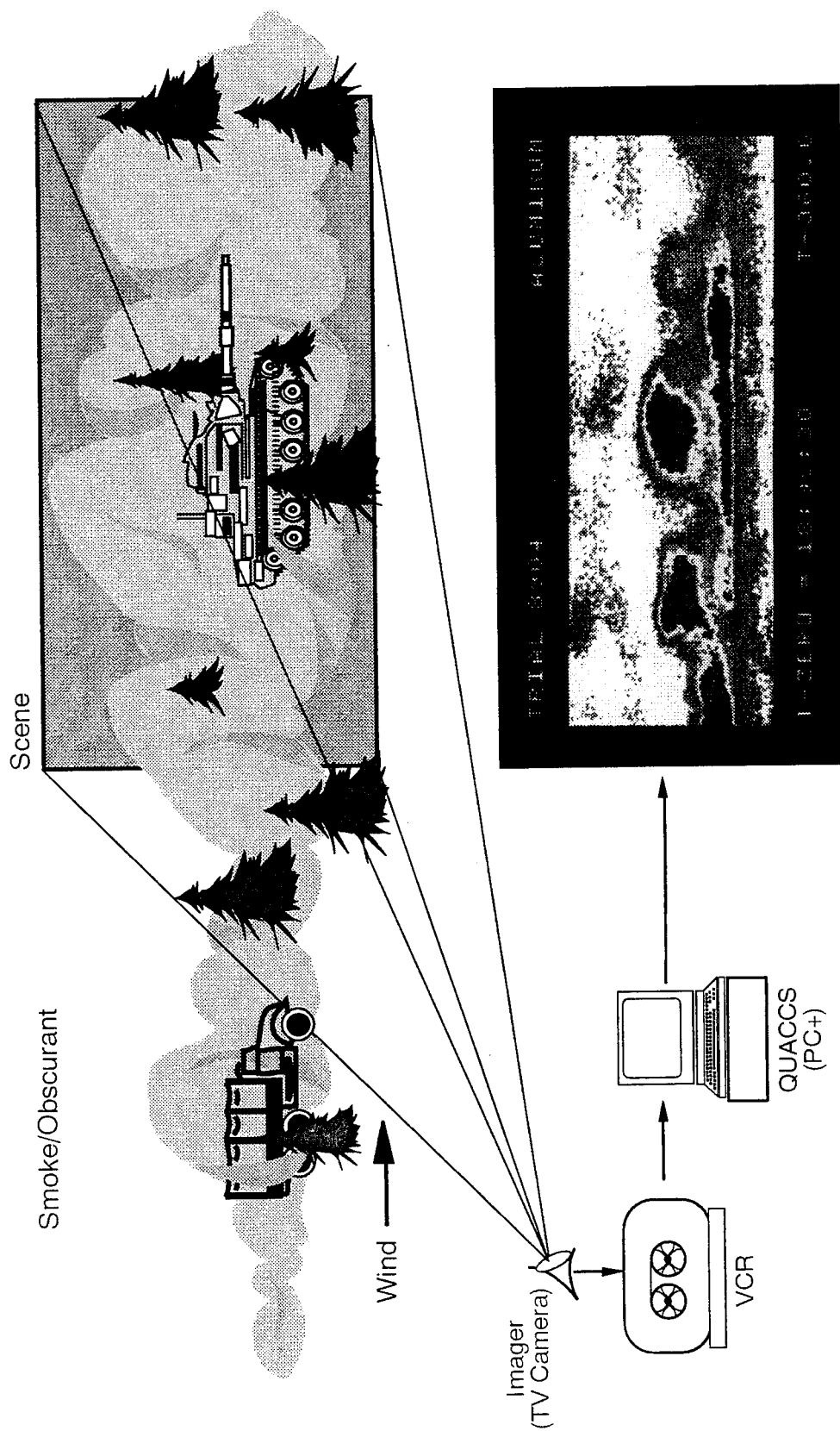


Figure 1. The ATLAS process shown schematically. The scene, containing a variety of natural and manmade objects, is imaged before and during the presence of smoke. The images, acquired with a thermal imager, are recorded to video tape for later data reduction that is accomplished with a pc-based image processing system.

2. Validation Process

The starting place for the validation process is analyses of the physics used in the ATLAS technique. For the physics, it was required that a detailed assessment be made of the radiative transfer process. As part of the assessment, it was necessary to determine the assumptions that were being made with the ATLAS algorithm and to define the limitations imposed on the process by those assumptions. Error analyses were performed and implemented because an important part of a validation procedure is knowing the errors of the measurement. The mitigation efforts that might be imposed to alleviate the limitations of ATLAS and ensure that the remaining assumptions are being addressed are discussed. The bulk of the analytical part of the validation process was carried out by Vonder Haar and associates at Colorado State University (CSU) and Metsat, Inc. These findings were presented in a series of reports and a symposium proceeding. [4,5,6,7] Empirical assessment was accomplished within the work unit and continues to advance with every new test; the efforts were presented at several symposia. [6,8,9]

2.1 Physics

The equation of radiative transfer (band-averaged) is given in equation (1):

$$N_R = N_c e^{-\tau} + (1-\omega)(1-e^{-\tau})B + \omega(1-e^{-\tau})N_e \quad (1)$$

where

- N_c = the clear air radiance of background scene element
- B = the Planck blackbody function of the cloud (cloud radiance)
- N_e = the environmental radiation that scatters off the cloud
- τ = the optical depth
- ω = the single scattering albedo

Because it is not practical to measure or know all the terms for ATLAS processing, assumptions concerning the relative importance of the various quantities must be made.

2.2 Assumptions

Because the measurements made during ATLAS data acquisition are in the far-IR portion of the electromagnetic spectrum, the following assumptions can be made to make the analyses more tractable:

1. A single scattering of background radiance is through the cloud; otherwise, the extinction involves multiple scattering that cannot be accounted for in the algorithm used for ATLAS processing.
2. The scattering portion of the extinction coefficient is small.
3. The background radiance is temporally constant.
4. The background radiance is sufficiently different from the cloud radiance.
5. The grey level is proportional to radiance.
6. Aerosol is at ambient temperature and the cloud is the same temperature everywhere, which implies that the cloud radiance is the same everywhere*.
7. The presence of smoke does not significantly affect the characteristics of the ambient clear atmosphere.

*Although the temperature in the atmosphere varies with height, no difference in cloud radiance with position in the cloud was detected, which could be ascribed to variable air temperature (this has not been formally documented).

The application of these assumptions allows equation (1) to be abbreviated to

$$N_R = N_C e^{-\tau} + (1 - e^{-\tau})B \quad (2)$$

or, rearranging,

$$T = \frac{N_R - B}{N_C - B} \quad (3)$$

where

$$T = e^{-\tau}, \quad (4)$$

which is what ATLAS measures, and B becomes the limiting cloud radiance under optically thick ($\tau \rightarrow \infty$) conditions.

2.3 Limitations

Ensuring that the assumptions are valid during the measurement process requires that limitations be placed on the use of the ATLAS technique. The limitations of the technique appear when the assumptions are no longer valid, and in fact, new assumptions are discovered as new limitations appear. ATLAS is not a cure-all and does not work in all instances; therefore, as it is used, new limitations will surface. The current inventory of major limitations consists of the following:

1. Unless the background scene radiance is much different from the cloud grey level, a measurement at that pixel location cannot be made, which can place holes in the data and make large regions of the image not available for analyses. The *a priori* determination of acceptable versus unacceptable test conditions is yet to be accomplished with certainty and laid down as a set of rules for test conduct.
2. Along with the first limitation, not only does the scene radiance need to be different from the cloud grey level, but it needs to be sufficiently different to allow meaningful measurements; the quantification of the required difference, *a priori*, remains to be accomplished. However, the

application of the error analyses algorithm allows the customer to select this parameter based on the error in the measurements, which is acceptable.

3. To use the ATLAS algorithm, the cloud grey level must be known. Usually, a target of opportunity coupled with a nearby background scene element can be used to arrive at that number. If there are no such hot spots, the analyses cannot proceed. Another way to get at the cloud grey level is to have a transmissometer along an LOS in the field of view, which is not always possible. Until a reliable, nonintrusive technique for determining cloud grey level is developed, determining cloud grey level will be a major limitation on processing of ATLAS data. This limitation is the primary reason real-time ATLAS is not successful; the tools (hardware and software) are there to process the images, etc. but not the *a priori* determination of cloud grey level.
4. Environmental (ambient) radiation scatters off the cloud into the field of view (path radiance) contributing a factor that cannot be accounted for with the current tools used in ATLAS analyses.
5. Background scene radiance is not constant with time.

In spite of these limitations and the lack of *a priori* information that allows a predetermination of the success or failure of test support, most of the time viable products are provided to the customer, and the concomitant learning process improves future products.

2.4 Error Analyses

The derivation of the error analyses is based on standard error analyses procedures delineated by Beers [10] and applied in the CSU/Metsat reports. The errors in output transmittance are due to error propagation from the ATLAS algorithm input variables. Input to the error analyses equations are estimates of the error absolute standard deviation. For the purposes of discussion, the ATLAS algorithm is restated with different symbols used for the variables:

$$T = \frac{GLC - GLS}{GLB - GLS} = \frac{N_R - B}{N_C - B} \quad (5)$$

where

GLC = the grey level of the current pixel location at the current time
 GLS = the grey level of the smoke cloud under optically thick conditions
 GLB = the grey level of the current pixel at some time before smoke in clear air.

The analyses only apply to this algorithm. If the ATLAS algorithm is modified, the error analyses must be updated. If one or more of the basic assumptions is seriously violated, the error analyses are meaningless (because different relationships among the variables will exist).

A discussion of the error estimates for each of the variables in equation (4) follows. The error estimates of GLC are made from the determination of radiometer accuracy (nominally 0.5 K -- for the gain setting used in this example) and effects of multiple scattering. For an instrument dynamic range of $\Delta T = 10$ K, the estimate in grey level counts (for 8 bits dynamic range = 256 grey levels) is $\approx \pm 13$ counts. The scattering effects are $\approx \pm 4$ counts. [6] Therefore, an example of the absolute standard deviation of GLC is given by

$$s_{GLC} = \sqrt{4^2 + 13^2} = \pm 13.6 \text{ counts} \quad (6)$$

The error estimate for GLB is primarily determined from radiometer accuracy. A way to reduce this value is to average several N clear air frames:

$$N \text{ images} \rightarrow \frac{1}{\sqrt{N}}(\pm 13) \quad (7)$$

(Significant averaging of frames to reduce s_{GLC} is not possible because the scene is dynamic during the presence of smoke and the averaging would wash out the dynamics of interest; however, there is some low-pass filtering required in the data reduction process to ensure that the results are presented without aliasing.)

The error estimate of GLS is derived from the procedures used to arrive at GLS. The best fit correlation can be used to produce a minimum absolute standard deviation; or an estimate of the scatter in the value can be made analytically or by eye. There may also be biases present in the determination of GLS because of the technique or some unaccounted for problem (such as stray path radiance). As better ways evolve to determine GLS, the error estimate should become more objective and, hopefully, smaller.

The calculation of the error needs to consider three separate cases because different procedures apply for each. The first is the case in which $GLC \neq GLS$. Equation (4) is rewritten as

$$x = GLC - GLS \quad (8)$$

$$y = GLB - GLS \quad (9)$$

$$T = \frac{x}{y}. \quad (10)$$

The absolute standard deviations of the ATLAS variables are used by

$$s_x = \sqrt{s_{GLC}^2 + s_{GLS}^2} \quad (11)$$

$$s_y = \sqrt{s_{GLB}^2 + s_{GLS}^2}. \quad (12)$$

The relative standard deviation is

$$s_t = T \sqrt{\left(\frac{s_y}{y}\right)^2 + \left(\frac{s_x}{x}\right)^2}. \quad (13)$$

For the second case, $GLC = GLS$ ($T = 0$ percent), equation (4) is rewritten as

$$x = \frac{GLC}{z} \quad (14)$$

$$y = \frac{GLS}{z} \quad (15)$$

$$z = GLB - GLS. \quad (16)$$

The absolute standard deviations of the ATLAS variables are used by

$$T = x - y \quad (17)$$

$$s_z = \sqrt{s_{GLB}^2 + s_{GLS}^2} \quad (18)$$

$$s_x = x \sqrt{\left(\frac{s_{GLC}}{GLC}\right)^2 + \left(\frac{s_z}{z}\right)^2} \quad (19)$$

$$s_y = y \sqrt{\left(\frac{s_{GLS}}{GLS}\right)^2 + \left(\frac{s_z}{z}\right)^2}. \quad (20)$$

The relative standard deviation for this case is

$$s_t = \sqrt{s_x^2 + s_y^2}. \quad (21)$$

For the third case, GLB = GLS, and the transmittance value is undefined; therefore, the error estimate S_T is also undefined.

A series of figures (2, 3, 4, and 5) is presented to show an input image, the resulting transmittance map, and the error map. The processing involves the application of equation (4) to each pixel in figures 2 and 3 to arrive at the map of figure 4. Each pixel in this series of images is processed with the error algorithms previously discussed to arrive at the error map of figure 5. An appreciation of the amount of processing required for a typical trial of 10 min duration is gained when it is realized that an 8-frame running average of the base video rate of 30 frames/s is performed, and every third frame is grabbed to provide 10 frames/s (low-pass filtering) for ATLAS processing, resulting in over 6000 images for further analysis.

In summary, if the basic ATLAS algorithm, equation (4), becomes modified, the error analyses must be updated. For example, when the imager is used to observe a target of opportunity or when a source is placed in the field of view (as is the case when the VORTEX* system [11] is implemented) and the Multipath Transmissometer Radiometer algorithm is used, a new set of equations must be developed. If any of the basic assumptions are violated, the output of the error analyses is meaningless.

*VORTEX is an acronym for a transmissometer system consisting of an imager as a receiver and an array of sources configured on a tower so that multiple LOSs in the vertical dimension (as opposed to the more usual horizontal dimension) may be measured.

2.5 Mitigation Efforts

Efforts to mitigate violated assumptions or lessen the impact of the limitations have primarily only reached the discussion stage because it is felt that mitigation efforts may be so intensive at this stage of ATLAS development that they would unnecessarily slow progress and delivery of the product to the customer. However, what has been discussed, accomplished, or is in progress will be presented next.

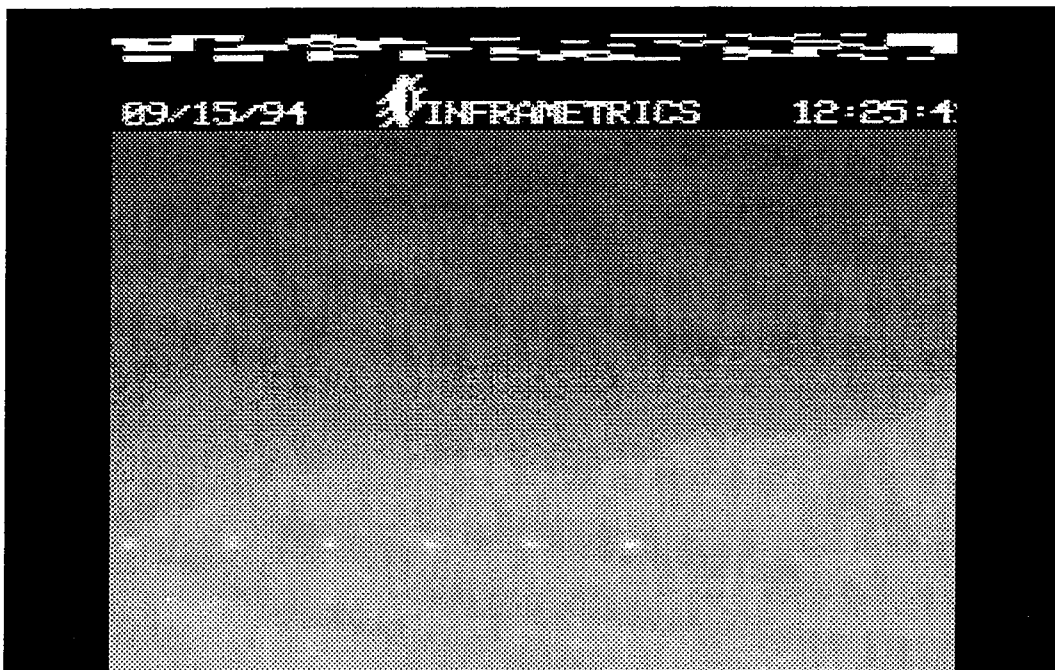


Figure 2. A pretrial image from a typical smoke trial. This scene provides the GLB used in the ATLAS algorithm. Each pixel location provides its unique grey level.

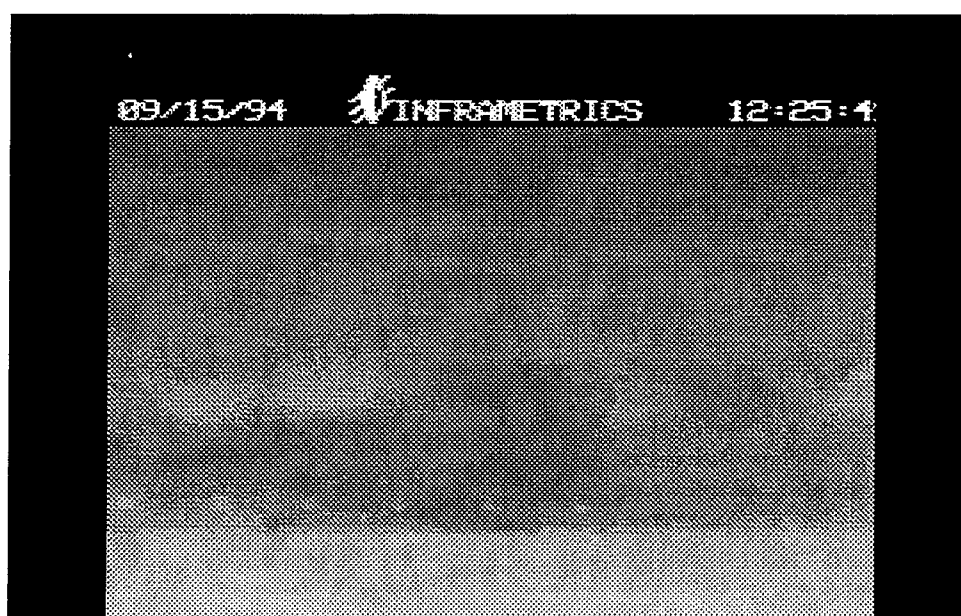


Figure 3. An image of the scene of figure 2 with smoke present. The grey level array provides the GLCs for equation (4).

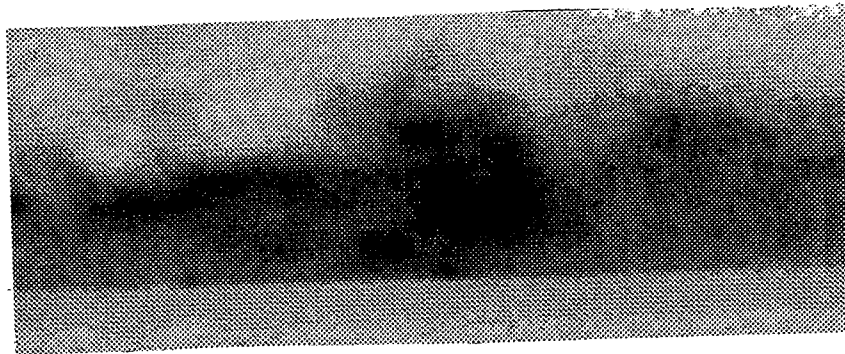


Figure 4. The transmittance map (transmittance in percent is proportional to grey level -- 0 percent is black and 100 percent is light grey) that results from the ATLAS processing of the images in figures 2 and 3. The cloud grey level, GLS, is a global constant and the same value applies everywhere in the image; therefore, there is no GLS image to correspond to those for GLC and GLB.

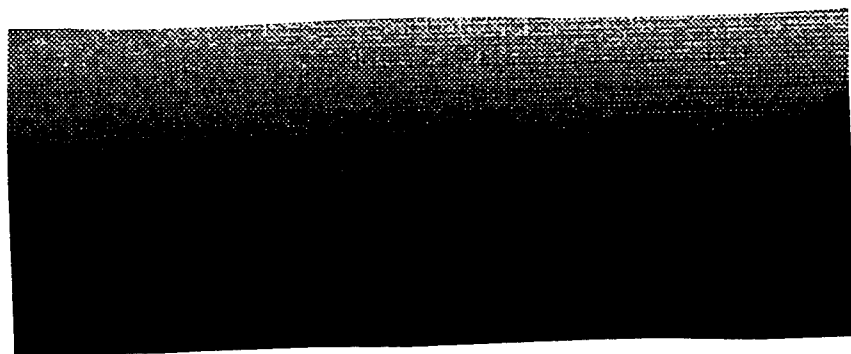


Figure 5. The error map that results from the application of the error analyses to this example shown in figures 2, 3, and 4. (Black is 0 percent error and white is equal to or greater than 243 percent error.) In theory, such a map should be provided with each transmittance image; in practice, only regions of large uncertainty are identified at the current time even though the capability exists to do the full analyses.

Two efforts are under way to understand and mitigate the limitation imposed by the temporal variation of the background radiance. To begin with, experience in the field has indicated that this may not be as severe a problem as one might think. On days of variable cloudiness, for example, the background radiance changes and instances of rapid fluctuations were observed; with no apparent cause. An example of this last situation is given by figure 6, which is a plot of grey level with time for a portion of a background scene observed in 1989. This observation was made under the following conditions:

- Time of day was approximately noon.
- Skies were clear (no clouds or haze).
- Location was Oscura Range (\approx 7000 ft elevation) (White Sands Missile Range (WSMR), NM).
- Transmissometers were positioned along the LOS.
- Visible videos in black and white and color were recorded.

From these conditions and observations (transmissometers and video observations indicated no changes from clear air conditions at the location with high altitude and clear, dry air at WSMR) it was concluded that there were no atmospheric fluctuations that could have caused the variation in background radiance. In addition, the variations were seen only in a portion of the image; therefore, it was not an imager problem. It is believed that the wind blowing up an arroyo caused changes in the transpiration and/or orientation of leaf structure of the vegetation, which caused a change in apparent radiance. In an attempt to better understand this type of problem and to assess its importance, a program of monitoring a local background scene at WSMR has been in place for about one and a half years. As part of this program, an environmental survey of the scene was conducted, and the tools necessary to reduce and understand the observations were obtained and developed. Two publications were produced by the effort. [12,13]

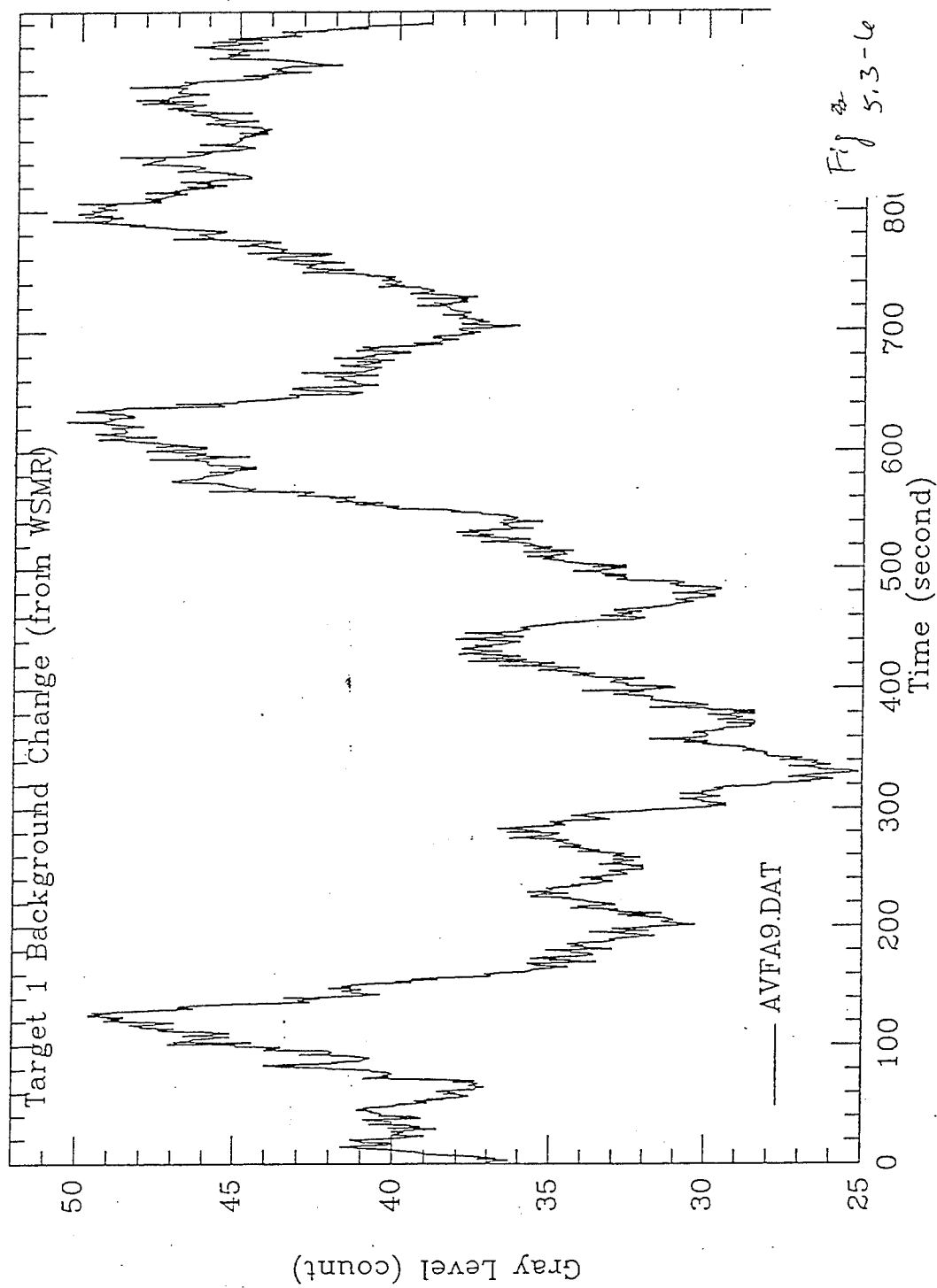


Figure 6. Rapid and large fluctuations in background radiance.

The other effort to mitigate variations in the background radiance is to use a millimeter wave (MMW) imaging system to observe the background radiance through visual and IR smokes and obscurants (note variations in radiance at MMW frequencies) and use the equations and models discussed to correct the IR radiance. This would serve another purpose; the imaging system could be used for ATLAS processing of MMW obscurants. The progress with this effort has been slow because of priorities. The receiver components and an antenna sufficient for single LOS observations were obtained and assembled. The next level of effort is to develop a scanning system for the radiometer so it can operate in an imaging mode. When fully developed, this system and follow-on systems will be useful for conducting scene radiance studies at MMW frequencies, characterizing MMW smokes and obscurants, and developing inclement weather surveillance systems. (Such systems could be placed in remotely piloted vehicles.)

Cloud radiance problems manifest themselves in two ways: in the determination of GLC and in which GLC is the same or nearly the same as the background radiance. The determination of GLC relies on a variety of intensive and interactive techniques. Efforts are underway to analyze the library of GLCs acquired to date to determine whether a more successful way of arriving at GLC, *a priori*, may be found. The problem of dynamic range $GLC \approx GLB$, may be overcome through judicious use of high-gain measurements; although, this will not work in all cases. A way around this is to estimate transmittance values in the region of uncertainty by using values from a nearby region and taking into account cloud movement; cloud structure remains sufficiently unchanged over small changes in time. As the situations that create this problem are better understood, test setup can be modified to eliminate the problem (observing from a different perspective to allow a different background).

When it is known that for a particular observation situation that scattering of environmental radiation by the cloud will affect the measurement, or that the cloud is self-emissive, use of sources in the field of view (see the VORTEX system description [11]) can allow modified ATLAS measurements. Use of VORTEX may allow a quantitative estimate of these effects so the error estimates may be properly made. Multispectral observations may identify scattering phenomena and, thus, assist in mitigation. Most of this is purely speculative; however, it holds promise for further development of ATLAS.

3. Conclusions

It has become more usual to discuss verification, validation, and accreditation, in particular, as applied to models. A presentation given at a recent Smoke/Obscurants Symposium, [14] defined these words to mean the following (paraphrased):

- verification: Does the model do what is expected; is arithmetic correct?
(happens first)
- validation: Does the model replicate what goes on in nature; how close?
- accreditation: Stamp of approval by the organization using or making the model that it has been verified and validated for a specific application and the conditions for which it was verified and validated.

In the context of what is presented in this report, all three of these processes have been completed and are documented here and discussed without discrimination as to the specific category (verification, validation, or accreditation) under scrutiny. The reason for using validation in generic terms has more to do with the accomplishment of a goal than a restriction of effort. Specifically, the verification process was the work accomplished by Vonder Haar and associates. The validation is the comparison of ATLAS data with more conventional transmissometer measurements in which the differences (basically, there are none) have been quantified and reported in two of the papers listed in the reference section. [8,9] Accreditation can include the portion of the previous discussion that describes the assumptions underlying the technique and the resulting limitation that this places on the use of ATLAS.

The ATLAS technique is continually under further development. With each new test situation, more is learned and improvements are made. ATLAS has been used to support numerous field tests and has been a key measurement for characterization of smoke/obscurant clouds. The documentation presented here shows ATLAS to be a viable process of which the full potential remains to be utilized.

References

1. Bleiweiss, M. P., R. A. Howerton, K. C. Payne, and T. A. King, "New Technique for Visualizing Three-Dimensional Flow in the Atmospheric Boundary Layer." In *Flow Visualization VI: Proceedings of the Sixth International Symposium on Flow Visualization*, Yokohama, Japan, Y. Tanida and H. Miyashiro (Eds.), Springer-Verlag Berlin Heidelberg, 1992.
2. Bleiweiss, M. P., K. C. Payne, and T. A. King, "CIRRUS: Real Smoke Clouds for Simulations and Simulators." In *Proceedings of the Smoke/Obscurant Symposium XVII*, U.S. Army Research Laboratory, WSMR, NM, 1993.
3. Alongi, R. E., Private communication, 1992.
4. Vonder Haar, T., G. Stephens, A. Jones, C. F. Shih, and J. Davis, *Analysis and Assessment of the Atmospheric Transmittance Large Area System (ATLAS)*, Final Report, Metsat, Inc., Fort Collins, CO, January 1990.
5. Vonder Haar, T., A. Jones, T. Wong, and C. Combs, *Extension and Implementation of Error Analysis Techniques Developed for the Atmospheric Transmission Large Area System (ATLAS)*, Final Report, Metsat, Inc., Fort Collins, CO, 15 February 1992.
6. Jones, A. S., T. H. Vonder Haar, and M. P. Bleiweiss, "An Assessment of an Infrared Imager Transmittance Measurement System." In *Proceedings of the Smoke/Obscurants Symposium XV*, U.S. Army Chemical Research Development and Engineering Center, Aberdeen Proving Ground, MD, April 1991.
7. Jones, A. S., C. L. Combs, and T. H. Vonder Haar, *Atmospheric Transmittance Large Area System (ATLAS) Transmittance Error Analysis Algorithm*, Metsat, Inc., Fort Collins, CO, 15 February 1992.

8. Bleiweiss, M., R. Howerton, R. Valdez, K. Payne, T. King, and K. Hutchison, "Comparison of the MPTR and ATLAS Transmissometers." In *Proceedings of the 11th Annual EOSAEL/TWI Conference*, U.S. Army Atmospheric Sciences Laboratory, WSMR, NM, 1990.
9. Bleiweiss, M., R. Howerton, R. Valdez, K. Payne, T. King, and K. Hutchison, "Comparison of the MPTR and ATLAS Transmissometers." In *Proceedings of the Smoke/Obscurant Symposium XV*, U.S. Army Chemical Research Development and Engineering Center, Aberdeen Proving Ground, MD, April 1991. (This was an expanded version of the EOSAEL/TWI paper of the same name.)
10. Beers, Y., *Introduction to the Theory of Errors*, Addison-Wesley Publishing Co., Inc., Reading, MA, 1957.
11. Bleiweiss, M. P., R. E. Davis, T. A. King, and K. C. Payne, "VORTEX: A New Tool for Observing Vertical Structure of Smoke/Obscurant Clouds." In *Proceedings of the 1992 Battlefield Atmospherics Conference*, U.S. Army Research Laboratory, WSMR, NM, 1992.
12. Nolen, B. and D. D. Bustamante, *A Review of Thermal Models and Site Data for the High Temporal Resolution Characterization of Natural Terrain Radiance Fluctuations at the MIDAS/ATLAS Site*, PSL-91/46, Physical Science Laboratory, New Mexico State University, Las Cruces, NM, October 1991.
13. Bustamante, D. D. and B. Nolen, *A Bibliography of Models and Model Parameters for Multispectral Remote Sensing at the MIDAS/ATLAS Site*, PSL-91/53, Physical Science Laboratory, New Mexico State University, Las Cruces, NM, October 1991.
14. O'Bryon, J. F., "Model Validation, Verification, and Accreditation (VVA)." In *Proceedings of the Smoke/Obscurants Symposium XVII*, U.S. Army Chemical and Biological Defense Agency, Aberdeen Proving Ground, MD, October 1993.

Acronyms and Abbreviations

ARL	Army Research Laboratory
ATLAS	Atmospheric Transmission Large-Area Analysis System
CSU	Colorado State University
IR	infrared
LOS	line of sight
MMW	millimeter wave
WSMR	White Sands Missile Range

Distribution

	Copies
ARMY CHEMICAL SCHOOL ATZN CM CC ATTN MR BARNES FT MCCLELLAN AL 36205-5020	1
NASA MARSHAL SPACE FLT CTR ATMOSPHERIC SCIENCES DIV E501 ATTN DR FICHTL HUNTSVILLE AL 35802	1
NASA SPACE FLT CTR ATMOSPHERIC SCIENCES DIV CODE ED 41 1 HUNTSVILLE AL 35812	1
ARMY STRAT DEFNS CMND CSSD SL L ATTN DR LILLY PO BOX 1500 HUNTSVILLE AL 35807-3801	1
ARMY MISSILE CMND AMSMI RD AC AD ATTN DR PETERSON REDSTONE ARSENAL AL 35898-5242	1
ARMY MISSILE CMND AMSMI RD AS SS ATTN MR H F ANDERSON REDSTONE ARSENAL AL 35898-5253	1
ARMY MISSILE CMND AMSMI RD AS SS ATTN MR B WILLIAMS REDSTONE ARSENAL AL 35898-5253	1

ARMY MISSILE CMND	1
AMSMI RD DE SE	
ATTN MR GORDON LILL JR	
REDSTONE ARSENAL	
AL 35898-5245	
 ARMY MISSILE CMND	 1
REDSTONE SCI INFO CTR	
AMSMI RD CS R DOC	
REDSTONE ARSENAL	
AL 35898-5241	
 ARMY MISSILE CMND	 1
AMSMI	
REDSTONE ARSENAL	
AL 35898-5253	
 ARMY INTEL CTR	 1
AND FT HUACHUCA	
ATSI CDC C	
FT HUACHUCA AZ 85613-7000	
 NORTHROP CORPORATION	 1
ELECTR SYST DIV	
ATTN MRS T BROHAUGH	
2301 W 120TH ST BOX 5032	
HAWTHORNE CA 90251-5032	
 NAVAL WEAPONS CTR	 1
CODE 3331	
ATTN DR SHLANTA	
CHINA LAKE CA 93555	
 PACIFIC MISSILE TEST CTR	 1
GEOPHYSICS DIV	
ATTN CODE 3250	
POINT MUGU CA 93042-5000	
 LOCKHEED MIS & SPACE CO	 1
ATTN KENNETH R HARDY	
ORG 91 01 B 255	
3251 HANOVER STREET	
PALO ALTO CA 94304-1191	

NAVAL OCEAN SYST CTR CODE 54 ATTN DR RICHTER SAN DIEGO CA 92152-5000	1
METEOROLOGIST IN CHARGE KWAJALEIN MISSILE RANGE PO BOX 67 APO SAN FRANCISCO CA 96555	1
DEPT OF COMMERCE CTR MOUNTAIN ADMINISTRATION SPRRT CTR LIBRARY R 51 325 S BROADWAY BOULDER CO 80303	1
DR HANS J LIEBE NTIA ITS S 3 325 S BROADWAY BOULDER CO 80303	1
NCAR LIBRARY SERIALS NATL CTR FOR ATMOS RSCH PO BOX 3000 BOULDER CO 80307-3000	1
DEPT OF COMMERCE CTR 325 S BROADWAY BOULDER CO 80303	1
DAMI POI WASH DC 20310-1067	1
MIL ASST FOR ENV SCI OFC OF THE UNDERSEC OF DEFNS FOR RSCH & ENGR R&AT E LS PENTAGON ROOM 3D129 WASH DC 20301-3080	1
DEAN RMD ATTN DR GOMEZ WASH DC 20314	1

SPACE NAVAL WARFARE SYST CMND PMW 145 1G WASH DC 20362-5100	1
ARMY INFANTRY ATSH CD CS OR ATTN DR E DUTOIT FT BENNING GA 30905-5090	1
AIR WEATHER SERVICE TECH LIBRARY FL4414 3 SCOTT AFB IL 62225-5458	1
USAFETAC DNE ATTN MR GLAUBER SCOTT AFB IL 62225-5008	1
HQ AWS DOO 1 SCOTT AFB IL 62225-5008	1
ARMY SPACE INSTITUTE ATTN ATZI SI 3 FT LEAVENWORTH KS 66027-5300	1
PHILLIPS LABORATORY PL LYP ATTN MR CHISHOLM HANSCOM AFB MA 01731-5000	1
ATMOSPHERIC SCI DIV GEOPHYSICS DIRCTRT PHILLIPS LABORATORY HANSCOM AFB MA 01731-5000	1
PHILLIPS LABORATORY PL LYP 3 HANSCOM AFB MA 01731-5000	1

RAYTHEON COMPANY ATTN DR SONNENSCHNEIN 528 BOSTON POST ROAD SUDBURY MA 01776 MAIL STOP 1K9	1
ARMY MATERIEL SYST ANALYSIS ACTIVITY AMXSY ATTN MP H COHEN APG MD 21005-5071	1
ARMY MATERIEL SYST ANALYSIS ACTIVITY AMXSY AT ATTN MR CAMPBELL APG MD 21005-5071	1
ARMY MATERIEL SYST ANALYSIS ACTIVITY AMXSY CR ATTN MR MARCHET APG MD 21005-5071	1
ARL CHEMICAL BIOLOGY NUC EFFECTS DIV AMSRL SL CO APG MD 21010-5423	1
ARMY MATERIEL SYST ANALYSIS ACTIVITY AMXSY APG MD 21005-5071	1
NAVAL RESEARCH LABORATORY CODE 4110 ATTN MR RUHNKE WASH DC 20375-5000	1
ARMY MATERIEL SYST ANALYSIS ACTIVITY AMXSY CS ATTN MR BRADLEY APG MD 21005-5071	1

ARMY RESEARCH LABORATORY AMSRL D 2800 POWDER MILL ROAD ADELPHI MD 20783-1145	1
ARMY RESEARCH LABORATORY AMSRL OP SD TP TECHNICAL PUBLISHING 2800 POWDER MILL ROAD ADELPHI MD 20783-1145	1
ARMY RESEARCH LABORATORY AMSRL OP CI SD TL 2800 POWDER MILL ROAD ADELPHI MD 20783-1145	1
ARMY RESEARCH LABORATORY AMSRL SS SH ATTN DR SZTANKAY 2800 POWDER MILL ROAD ADELPHI MD 20783-1145	1
ARMY RESEARCH LABORATORY AMSRL 2800 POWDER MILL ROAD ADELPHI MD 20783-1145	1
NATIONAL SECURITY AGCY W21 ATTN DR LONGBOTHUM 9800 SAVAGE ROAD FT GEORGE G MEADE MD 20755-6000	1
ARMY AVIATION CTR ATZQ D MA ATTN MR HEATH FT RUCKER AL 36362	1
OIC NAVSWC TECH LIBRARY CODE E 232 SILVER SPRINGS MD 20903-5000	1

ARMY RSRC OFC ATTN DRXRO GS PO BOX 12211 RTP NC 27009	1
DR JERRY DAVIS NCSU PO BOX 8208 RALEIGH NC 27650-8208	1
ARMY CCREL CECRL GP ATTN DR DETSCH HANOVER NH 03755-1290	1
ARMY ARDEC SMCAR IMI I BLDG 59 DOVER NJ 07806-5000	1
ARMY COMMUNICATION ELECTR CTR FOR EW RSTA AMSEL RD EW SP FT MONMOUTH NJ 07703-5206	1
ARMY SATELLITE COMM AGCY DRCPM SC 3 FT MONMOUTH NJ 07703-5303	1
ARMY COMMUNICATIONS ELECTR CTR FOR EW RSTA AMSEL EW D FT MONMOUTH NJ 07703-5303	1
ARMY COMMUNICATIONS ELECTR CTR FOR EW RSTA AMSEL EW MD FT MONMOUTH NJ 07703-5303	1
ARMY DUGWAY PROVING GRD STEDP MT DA L 3 DUGWAY UT 84022-5000	1

ARMY DUGWAY PROVING GRD STEDP MT M ATTN MR BOWERS DUGWAY UT 84022-5000	1
DEPT OF THE AIR FORCE OL A 2D WEATHER SQUAD MAC HOLLOMAN AFB NM 88330-5000	1
PL WE KIRTLAND AFB NM 87118-6008	1
USAF ROME LAB TECH CORRIDOR W STE 262 RL SUL 26 ELECTR PKWY BLD 106 GRIFFISS AFB NY 13441-4514	1
AFMC DOW WRIGHT PATTERSON AFB OH 0334-5000	1
ARMY FIELD ARTLLRY SCHOOL ATSF TSM TA FT SILL OK 73503-5600	1
NAVAL AIR DEV CTR CODE 5012 ATTN AL SALIK WARMINISTER PA 18974	1
ARMY FOREGN SCI TECH CTR CM 220 7TH STREET NE CHARLOTTESVILLE VA 22901-5396	1
NAVAL SURFACE WEAPONS CTR CODE G63 DAHLGREN VA 22448-5000	1

ARMY OEC CSTE EFS PARK CENTER IV 4501 FORD AVE ALEXANDRIA VA 22302-1458	1
ARMY CORPS OF ENGRS ENGR TOPOGRAPHICS LAB ETL GS LB FT BELVOIR VA 22060	1
TAC DOWP LANGLEY AFB VA 23665-5524	1
ARMY TOPO ENGR CTR CETEC ZC 1 FT BELVOIR VA 22060-5546	1
LOGISTICS CTR ATCL CE FT LEE VA 23801-6000	1
SCI AND TECHNOLOGY 101 RESEARCH DRIVE HAMPTON VA 23666-1340	1
ARMY NUCLEAR CML AGCY MONA ZB BLDG 2073 SPRINGFIELD VA 22150-3198	1
ARMY FIELD ARTLLRY SCHOOL ATSF F FD FT SILL OK 73503-5600	1
USATRADO ATCD FA FT MONROE VA 23651-5170	1
ARMY TRADOC ANALYSIS CTR ATRC WSS R WSMR NM 88002-5502	1

ARMY RESEARCH LABORATORY AMSRL BE M BATTLEFIELD ENVIR DIR WSMR NM 88002-5501	1
ARMY RESEARCH LABORATORY AMSRL BE A BATTLEFIELD ENVIR DIR WSMR NM 88002-5501	1
ARMY RESEARCH LABORATORY AMSRL BE W BATTLEFIELD ENVIR DIR WSMR NM 88002-5501	1
ARMY RESEARCH LABORATORY AMSRL BE ATTN MR VEAZEY BATTLEFIELD ENVIR DIR WSMR NM 88002-5501	1
DEFNS TECH INFO CTR CENTER DTIC BLS BLDG 5 CAMERON STATION ALEXANDRIA VA 22304-6145	1
ARMY COMMUNICATIONS ELECTR CTR FOR EW RSTA AMSEL FT MONMOUTH NJ 07703-5303	1
ARMY MISSILE CMND AMSMI REDSTONE ARSENAL AL 35898-5243	1
ARMY DUGWAY PROVING GRD STEDP 3 DUGWAY UT 84022-5000	1

ARMY COMMUNICATIONS ELECTR CTR FOR EW RSTA AMSEL FT MONMOUTH NJ 07703-5206	1
USATRADO ATCD FA FT MONROE VA 23651-5170	1
ARMY FIELD ARTLRY SCHOOL ATSF FT SILL OK 73503-5600	1
WSMR TECH LIBRARY BR STEWIS IM IT WSMR NM 88001	1
ARMY RESEARCH LABORATORY AMSRL SL CO ATTN MR R LAUGHMAN APG MD 21010-5423	1
ARMY RESEARCH LABORATORY AMSRL SL CO ATTN MR W G KLIMEK APG MD 21010-5423	1
ARMY RESEARCH LABORATORY AMSRL SL CO ATTN MR A VAN DE WAL APG MD 21010-5423	1
ARMY RESEARCH LABORATORY AMSRL SL CO ATTN MR R HOWERTON WSMR NM 88002	1
ARMY RESEARCH LABORATORY AMSRL SL CO ATTN MR R DE KINDER WSMR NM 88002	1

ARMY RESEARCH LABORATORY AMSRL SL CO ATTN MR J E BUTTERFIELD WSMR NM 88002	1
MR J SERNA NMSU PSL LAS CRUCES NM 88003	1
MS J ESPARZA NMSU PSL LAS CRUCES NM 88003	1
MR D STOGDEN NMSU PSL LAS CRUCES NM 88003	1
MR T KING NMSU PSL LAS CRUCES NM 88003	1
MR K PAYNE NMSU PSL LAS CRUCES NM 88003	1
DR THOMAS VONDER HAAR STC METSAT 515 SOUTH HOWES STREET FORT COLLINS CO 80521	1
ARMY RESEARCH LABORATORY AMSRL BE S ATTN DR D HOOCK WSMR NM 88002-5501	1
ARMY RESEARCH LABORATORY AMSRL BE S ATTN DR J GILLESPIE WSMR NM 88002-5501	1

ARMY RESEARCH LABORATORY AMSRL BE E ATTN DR D GARVEY WSMR NM 88002-5501	1
ARMY RESEARCH LABORATORY AMSRL BE S ATTN DR R SHIRKEY WSMR NM 88002-5501	1
ARMY EDGEWOOD RESEARCH DEV AND ENGIN CTR SCBRD CE ATTN MS C KILGORE WOLF APG MD 21010-5423	1
ARMY EDGEWOOD RESEARCH DEV AND ENGIN CTR SCBRD CE ATTN MR J MOORE APG MD 21010-5423	1
ARMY EDGEWOOD RESEARCH DEV AND ENGIN CTR SCBRD RT ATTN MR D PRAPAS APG MD 21010-5423	1
PROJECT MANAGER SMOKES AND OBSCURANTS AMCPM SM APG MD 21010-5423	1
ARMY EDGEWOOD RESEARCH DEV AND ENGIN CTR SCBRD EN ATTN MR R RHEA APG MD 21010-5423	1
ARMY EDGEWOOD RESEARCH DEV AND ENGIN CTR SCBRD EN ATTN MR WILLIAM G. ROUSE APG MD 21010-5423	1

MR BENJAMIN PERRY IV GEORGIA TECH RES INSTITUTE BLDG 5 108 7220 RICHARDSON RD SMYRNA GA 30080	1
MR MARK PERRY BATTELLE 505 KING AVENUE COLUMBUS OH 43201	1
MR G BLACKMAN 1455 TIERRA DEL SOL DRIVE LAS CRUCES NM 88005	1
DR R DAVIS SCIENCE AND TECHNOLOGY CORP 555 S TELSHOR BLVD SUITE 200 LAS CRUCES NM 88011	1
HQ TEST AND EXPER CMND CSTE TES ATTN MR RICK JERNIGAN FORT HOOD TX 76544-5065	1
DR W MICHAEL FARMER THE INCA GROUP FNB SUITE 900 500 S MAIN LAS CRUCES NM 88001	1
MR R STOUT OPTIMETRICS INC 2107 LAUREL BUSH ROAD SUITE 209 BEL AIR MD 21015	1
HQDA SAUS OR ATTN DR ROBERT HINKLE THE PENTAGON 1E643 WASHINGTON DC 20310-0102	1

DR JOHN MOLITARIS LAWRENCE LIVERMORE NATL LAB PO BOX 808 MS L 262 LIVERMORE CA 94550	1
ARMY DUGWAY PROVING GROUND STEDP WD TS AV ATTN MR J YALE DUGWAY UT 84022-5000	1
ARMY DUGWAY PROVING GROUND STEDP WD TM MO ATTN MR D BODRERO DUGWAY UT 84022-5000	1
ARMY DUGWAY PROVING GROUND STEDP WD TM ATTN MR L CARTER DUGWAY UT 84022-5000	1
ARMY DUGWAY PROVING GROUND STEDP WD M ATTN MR C BILTOFT DUGWAY UT 84022-5000	1
ARMY DUGWAY PROVING GROUND STEDP WD TS ATTN MR W DWYER DUGWAY UT 84022-5000	1
ARMY DUGWAY PROVING GROUND STEDP WD M ATTN MR J BOWERS DUGWAY UT 84022-5000	1
MR R BERGER ARMY COLD REGIONS RESEARCH AND ENGINEERING LABORATORY 72 LYME ROAD HANOVER NH 03755	1

PROJECT MANAGER	1
NBC DEFENSE SYSTEMS	
AMCPM NN	
APG MD 21010-5423	
Record Copy	20
TOTAL	149